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INFLUENCE OF EARTHQUAKE SOURCE PARAMETERS AND DAMPING ON ELASTIC RESPONSE SPECTRA

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ABSTRACT

In this paper the influence of effective duration of strong motion, soil condition, magnitude and shape of accelerogram time history on elastic response spectra have been investigated. A total of 106 Iran's horizontal acceleration components strong motion records are selected. These accelerograms are categorized in accordance with their earthquake parameters and soil condition of recording station and the influence of different soil conditions are plotted in graphs. The influence of damping ratio on the response spectra is also investigated. Analytical results show that the influence of soil condition is very significant on the shape of response spectra. The influence of effective duration of strong motion has been studied by definition based on energy of accelerogram. It can be seen that an increase in effective duration, causes reduction in the slope of response spectra in long period part and increases the spectral values. The effect of damping on response spectra is presented by special coefficient, which depends on the period of the structure, soil condition and damping ratio.

1. INTRODUCTION

Response spectrum is the most suitable tool developed so far for expressing the excitation response relationship in earthquake engineering and seismic design. Although it is an indirect measure of ground motion intensity, it expresses maximum response directly, which is a major concern in design.

If one generates sets of response spectrum curves for ground motions recorded at different locations during past earthquakes, large variation will be observed in both the response spectral values and the shape of the spectrum curves from one set to another. These variations depend upon many factors such as energy release mechanism in the vicinity of the focus or hypocenter and along fault interfaces, epicentral distance and focal depth, geology and variations in geology along energy transmission paths, Richter magnitude and local soil conditions at the recording station. Thus the response spectral values S (S_{pv}, S_{pa} and S_d) for earthquake ground motion should be thought of in the form [Clough and Penzien, 1993]

$$S = S\,(SM, ED, FD, GC, M, SC, \xi, T)$$

Where the independent variables denote source mechanism, epicentral distance, focal depth, geological conditions, Richter magnitude, soil conditions, damping ratio and period, respectively. The effects of SM and GC on both spectral values and shapes of the response spectrum curves are not well understood; therefore such effects cannot be quantified when defining response spectra for design purposes. The effects of ED, FD and M are usually taken into consideration while specifying the intensity levels of the design response spectra; however, they are often ignored during specifying the shape of these spectra because of lack of knowledge as to their influences. On the other hand the effects of SC on both the intensities and shapes of response spectra are now being considered widely for defining design response spectra.

In addition to plotting response spectra on tripartite (four way logarithmic) scales for S_d, $S_{pv} = \omega S_d$ and $S_{pa} = \omega^2 S_d$, it is sometimes convenient to plot the ratio of the response to the appropriate ground motion (amplification). In many cases the ratio of spectral acceleration to peak ground acceleration (acceleration amplification) is plotted as a function of either frequency or period.

In this study the effect of soil condition, magnitude and epicentral distance of the earthquake and damping ratio of the system on response spectra is considered. In addition to these parameters, the effect of time duration of strong motion is evaluated. The time duration of strong motion for earthquakes is calculated from the definition of Trifunac and Brady [1975] and is pointed out in reference [Tehranizadeh and Hamedi, 1999]. For evaluating the effect of shape of accelerogram's time history, the records are grouped in accordance with their peak ground accelerations (PGA) and the influence of this parameter is also shown.

In this study 106 Iran's earthquakes strong motion records are used. These accelerograms are selected from the "Basic Accelerograms Data of the Iranian Accelerographs Network" [Ramazi, 1997]. In this selection the records which their soil conditions have been determined by geophysical (geoseismical and geoelectrical) observations are chosen (type A). Longitudinal and transverse components with maximum ground accelerations(greater than 50 gal) are used.

2. EFFECT OF TIME DURATION OF STRONG MOTION ON RESPONSE SPECTRA

The records are divided in 5 groups for this evaluation. The time duration of strong motion is the time interval, which takes place between 5% to 95% of total accelerogram's energy. This time is pointed out [Tehranizadeh and Hamedi 1999] for the selected records. The time duration is between 0.18 to 39.24 seconds for these records and the records are grouped as:

Type (a): time duration between 0 to 2 seconds; 24 records
Type (b): time duration between 2 to 4 seconds; 25 records
Type (c): time duration between 4 to 6 seconds; 18 records
Type (d): time duration between 6 to 10 seconds; 23 records
Type (e): time duration longer than 10 seconds; 18 records

In Figure 1 average and mean plus one standard deviation values for first group, it means with time duration between 0 to 2 sec, are plotted. In this diagram the logarithms of pseudo velocity S_{pv} is drawn with the logarithms of the structure's period. Curve (a) shows the average spectral values (50 percentile) and curve (b) shows the mean plus one standard deviation (84.1 percentile). The shape of spectra is very sharp with a maximum at period 0.2 second. For smaller periods the two curves are very close together and differences would be increased for longer periods. This Figure shows that structures with period near 0.2 seconds (two-story structures) are very sensitive to earthquakes with short time durations.

Figure 2 shows the average and Figure 3 shows the mean plus one standard deviation for all five groups of time durations. Curves (a) to (e) show each group respectively. Curves (a) to (d) have a maximum at period 0.2 second but the curves (b) to (d) have smaller slopes and are flatter than curve (a). When the time duration of strong motion increases and is longer than 10 seconds, the maximum is on the period of nearly 1.0 seconds, so the short structures (nearly 2-storey) are sensitive to

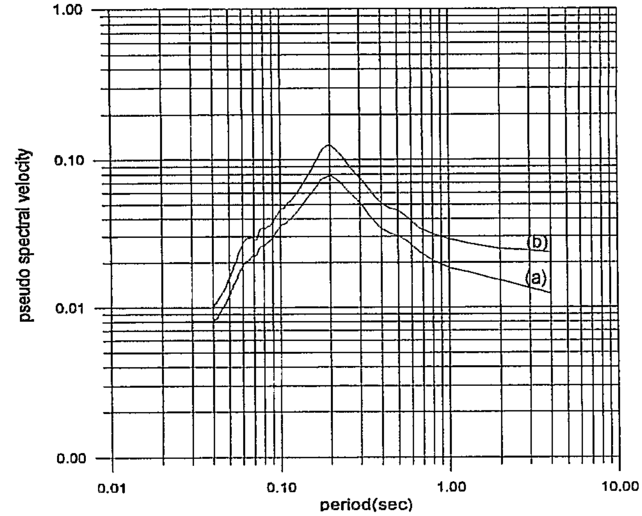

Fig. 1: Average and mean plus one standard deviation for Earthquakes with 0 to 2 second duration

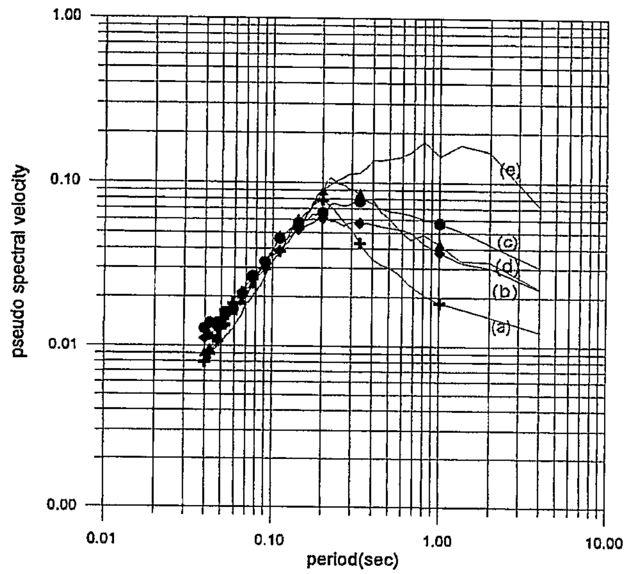

Fig 2: Average of five groups of earthquakes with different time durations

earthquakes which their time duration of strong motion is shorter than 10 seconds and medium to tall structures (nearly 10-storey) are sensitive to earthquakes with time duration longer than 10 sec. In Iranian code for design of structure for seismic loadings, it has been noted that for time history analysis of structures, the designer must use the records of earthquakes with time duration of strong motions longer than 10 seconds. This would be somewhat under design for small structures and over-estimate for medium to tall structures.

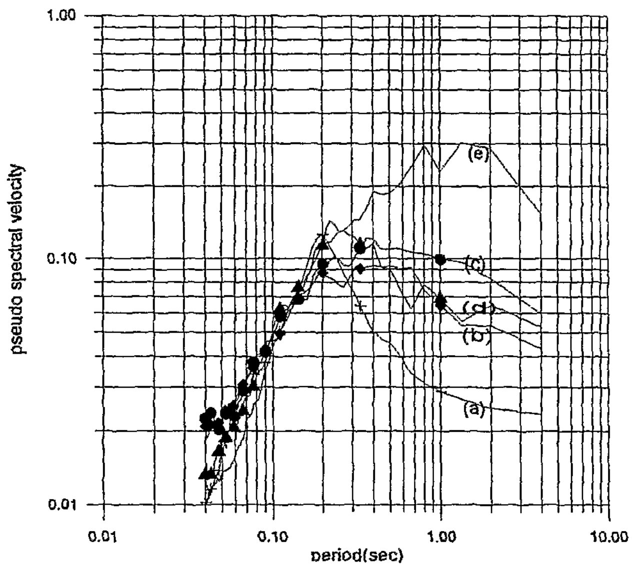

Fig 3: Mean plus one standard deviation for five group of earthquakes with different time duration

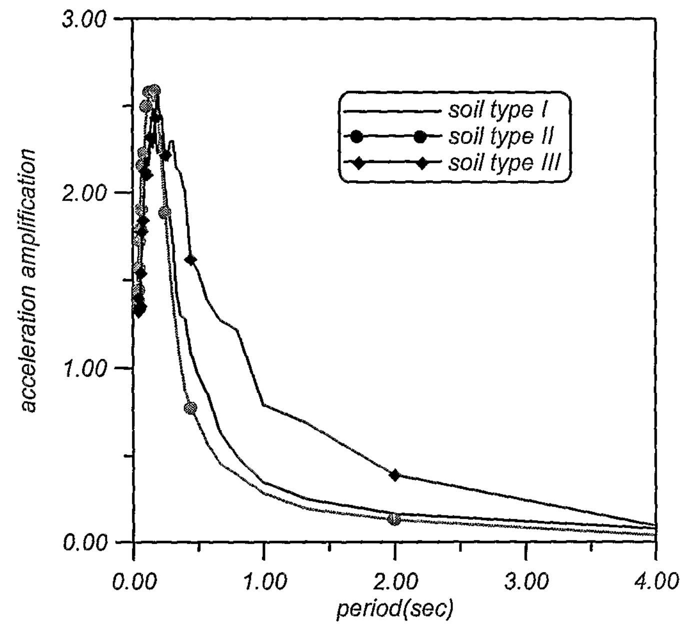

Fig 4: Average acceleration spectra for all soil types.

The influence of duration of strong motion on response spectra has been studied by Pang et al., [1989] who compared acceleration amplifications for earthquakes with 5, 10 and 20 seconds duration with that of SEAOC and showed that a longer duration of strong motion increases the response in the low and intermediate frequency regions. This is consistent with the fact that accelerograms with long duration of strong motion have a greater probability of containing long period waves which can result in a higher response in the long-period (low frequency) region of The spectrum [Mohraz and Elghadamsi, 1989].

3. EFFECT OF SOIL CONDITION ON RESPONSE SPECTRA

Prior to the San Fernando earthquake of 1971, accelerograms from pervious earthquakes were limited in number, and the majority was recorded on alluvium [Mohraz and Elghadamsi 1989]. But after that many researchers work on the influence of soil condition on response and design spectra. Seed et al., [1976] and Mohraz [1976] have curves, which show the effect of different soil types on acceleration amplification. In the study by seed a total of 104 horizontal component of earthquake records have been used and they show that the average value of acceleration amplification for a soil type like soil type No II of Iranian code would ha ve the maximum value of 2.9. For softer soils the curves would be flatter and for periods greater Than approximately 0.4-0.5 seconds, the acceleration amplification for rock are substantially below those for soft to medium clay and for deep cohesion less soil, so using the spectra from the latter two groups may overestimate the design amplifications for rock.

In this study the records are divided in accordance with the station soil type. This classification is on the basis of Iranian code of practice for seismic resistant design of buildings. According to Iranian code four different groups of soil are defined as follow:

I: rock and very stiff soil ($V_S > 750$ m/s)

II: Stiff soil ($375 < V_S < 750$)

III: soft soil ($175 < V_S < 375$)

IV: very soft soil ($V_S < 175$ m/s)

The stations under consideration have a minimum shear wave velocity of 210 m/sec (Rudsar). So three types of soils, it means rock and very stiff soil, stiff soil, and soft soil is considered. With these soil types there are 31 records on type I, 52 records on type II, and 23 records on type III.

Figure 4 shows the effect of soil condition on response spectra for all of the records. The average of spectral acceleration for each soil groups is shown. As can be seen from the figure the response spectra for soil type I has a maximum of 2.55 at a period of nearly 0.2 second and the curve has great slopes on both sides of this point. For soil type II the slopes are as for type I, but a maximum of 2.65. It means that acceleration is somewhat larger for type II than type I. (The same result as Seed et al. 1976). Soil type III have similar slope for periods smaller than 0.2. The maximum of curve in this case is 2.60

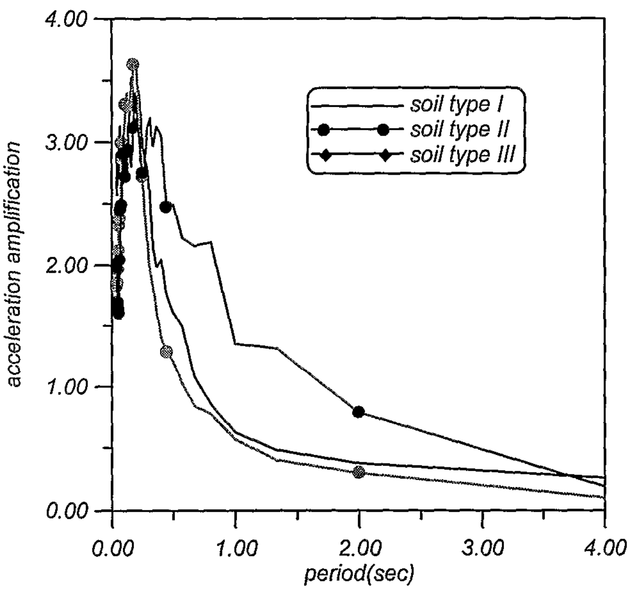

Fig 5: Mean plus one standard deviation acceleration spectra for all soil types

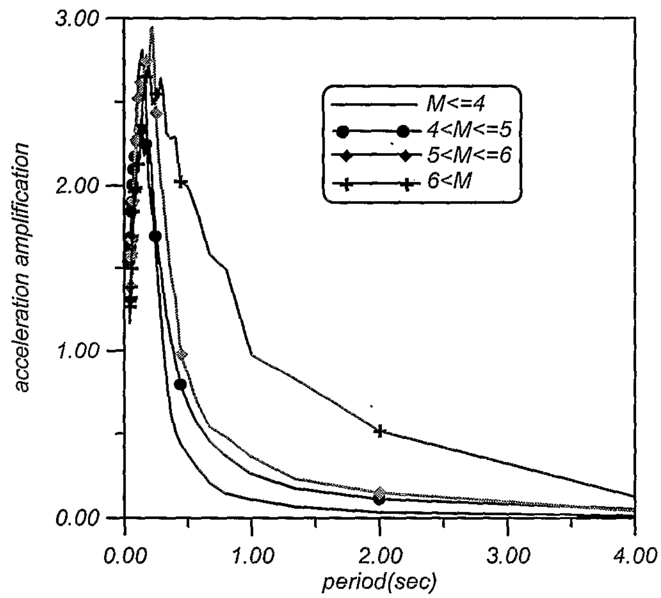

Fig 6: Average acceleration spectra for different earthquake magnitudes

and the shape of designing portion is much smaller than type I or II. The spectral values are very large and almost equal the maximum value for a wide period range, for structures with period of 0.2 to 0.4 seconds. For large periods (nearly 4 seconds) all the four soil types have nearly equal values.

Figure 5 shows the mean plus one standard deviation of spectral acceleration for each soil groups. Comparing with figure 4 it has greater spectral values, which reaches 3.75 for soil type II. The variation of acceleration and spectral curve shape is like figure 4, which is drawn for 50 percentile. For soft soils either the maximum value or the slope of curve for periods longer than 0.2 seconds decreases, therefore the acceleration amplification is greater for soft soils than stiff soils in periods between 0.2 and 4.0. Soil types I and II shows nearly equal values in this region.

4. EFFECT OF EARTHQUAKE MAGNITUDE ON RESPONSE SPECTRA

The earthquake magnitude influences the response spectral shape and values. A study by Mohraz [1978] on the influence of earthquake magnitude on response amplification for alluvium shows larger acceleration amplifications for records with magnitude between 6 and 7 than for those with magnitudes between 5 and 6. They show that this effect may need to be considered when developing design spectra for a specific site, particularly for critical structures.

In this study the records are grouped in accordance to their magnitude. 15 records have magnitude smaller than 4, 49 records have magnitude between 4 and 5, 19 records are between 5 and 6; and finally 23 records with magnitude greater than 6. So four groups are specified. Figure 6 shows the effect of magnitude on response spectra for these four groups. For high frequency structures, the acceleration amplification decreases slightly with an increase in earthquake magnitude so for structures with periods smaller than 0.2 the acceleration amplification dose not depend on magnitude of earthquakes. Medium and high-rise structures are more sensitive to earthquake with high magnitude especially with magnitudes over 6.

5. EFFECT OF EPICENTRAL DISTANCE ON RESPONSE SPECTRA

In order to investigate the effect of epicentral to site distance the records are grouped according to their epicentral distance. There are 7 records with epicentral distance smaller than 10 Km, 7 records with 10 to 15 Km, 10 records with 15 to 20 Km, 24 records with 20 to 30 Km, 27 records with 30 to 50 Km, and 21 records with epicentral distance more than 50 Km. The Average response spectra for each group have been calculated and are shown in figure 7. For almost all periods the spectral values are decreased with an increase in epicentral distance. So if the site is near the earthquake source the spectral values are greater for distances between 10 to 50 Km. the spectral values are smaller than the corresponding value for distances greater than 50 Km.

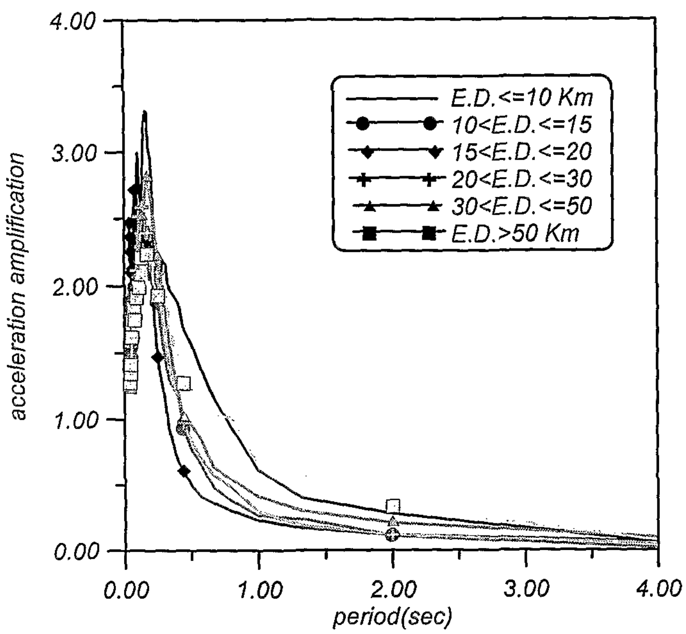

Fig 7: Average acceleration spectra for different epicentral distances

6. EFFECT OF ACCELEROGRAM SHAPE ON RESPONSE SPECTRA

In order to show the effect of accelerogram shape on response spectra the records are grouped on the basis of their PGA. It is noted that each accelerograms ordinate is divided to the PGA ofthat accelerogram before calculating the response spectra, so the accelerograms are normalized and the response spectra's are for a unit acceleration. So the results of this study are not applicable to spectra values but the spectral shape. In this study the records are grouped in 5 groups as follow:

$50 \le PGA < 70 \rightarrow 25$ records
$70 \le PGA < 90 \rightarrow 21$ records
$90 \le PGA < 150 \rightarrow 21$ records
$150 \le PGA < 250 \rightarrow 21$ records
$PGA \ge 250 \rightarrow 18$ records

Comparing the response spectral shape of these groups' shows that nearly all of them have a same trend and the response spectra is not dependent on the variation of accelerograms with time.

7. EFFECT OF DAMPING RATIO ON RESPONSE SPECTRA

Damping ratio is one of the effective parameters on response spectra. The spectral values decreases with an increase in damping ratio. In this work the response spectra of each accelerogram has been calculated for five different damping ratios, 0,2,5,7,and 10 percent. Figure 8 shows the effect of damping ratio on response spectra for two different soil types. These are the average (probability %50) response spectra. For small damping ratios and especially for periods smaller than 0.5 seconds, an increase in damping ratio significantly decreases the spectral values. For example the ratio of spectral values for zero percent to the corresponding value for two percent damping ratio for a period of 0.15 seconds are very large and equals nearly 1.9, but at this same period the ratio of spectral values for %5 to %7 damping is equal to 1.13. These rates decrease for longer periods.

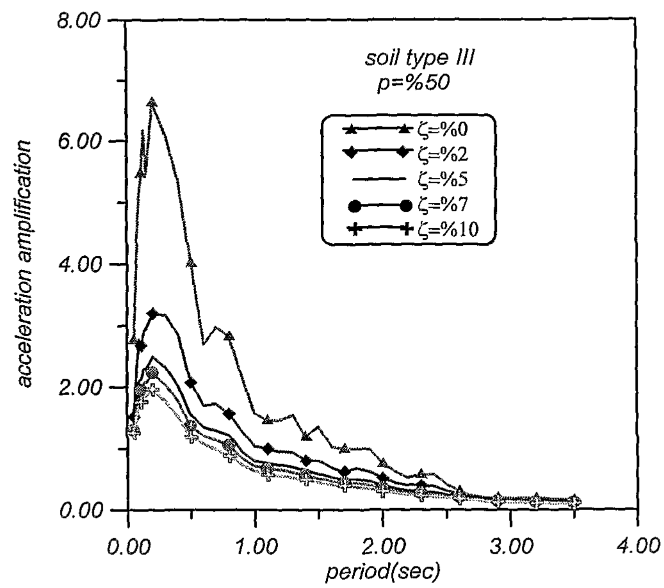

Fig 8: Average acceleration spectra for different damping ratios

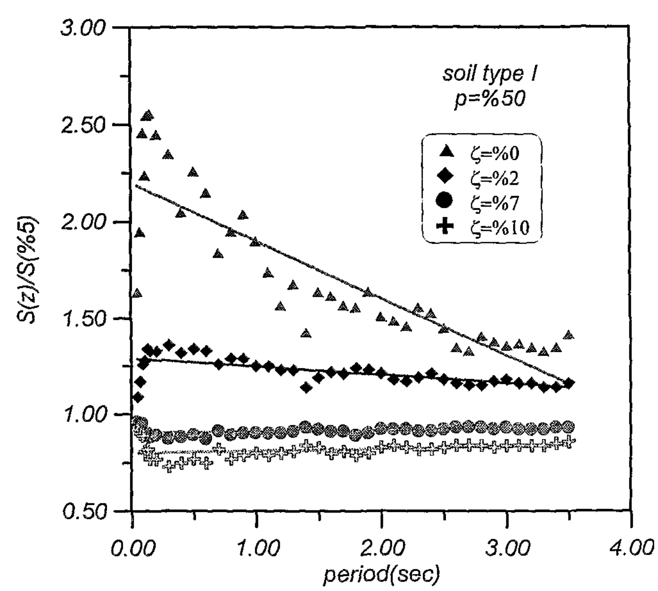

Fig 9 : Effect of damping ratio on C_Z for soil type I

Table 1: Value of a_Z and b_Z for determining damping modifying coefficient C_Z

Soil type	%0		%2		%7		%10	
	a_Z	b_Z	a_Z	b_Z	a_Z	b_Z	a_Z	b_Z
I	-0.298	2.20	-0.043	1.29	0.0069	0.90	0.0110	0.80
II	-0.147	1.82	-0.024	1.23	0.0047	0.91	0.0058	0.83
III	-0.360	2.54	-0.040	1.33	0.0110	0.89	0.0220	0.77

In this paper the base response spectra is drawn for %5damping ratio and for other values of damping the base spectral values are modified with a coefficient. The modifying coefficient, Cz, is the ratio of the spectral value for ζ percent damping to the spectral value of 5 percent.

$$C_Z = {}^{S_\zeta}\!/\!{}_{S_{\%5}}$$

In order to determine C_Z, the spectral values for 0,2,7, and 10 percent damping are divided to the corresponding value for 5 percent damping for each soil type and for different periods. Figure 9 shows the effect of period on the value of C_Z for different damping ratios and for soil type I. For very short periods and for damping ratios smaller than %5, an increase in period causes a sharp increase in C_Z, but it decreases rapidly after that. A line with negative slope is used to show the changes of C_Z with period. Defining the changes of C_Z with period as a straight line we can write:

$$C_Z = a_Z.T + b_Z$$

The parameters a_Z and b_Z which depend on soil type and damping ratio, are determined and presented in table 1.

8. CONCLUSION

1. An increase in time duration of strong motion causes the response spectra to be flatter and have smaller slope, so for most periods an increase in time duration causes greater spectral values.
2. The spectral shape is very sharp for average (50 percentile) value for soil types I and has a maximum of 2.55 at period 0.2 seconds. For soft soils the spectral curve is flatter and have a maximum of 2.6.
3. The 84.1 percentile mean plus one standard deviation curve has a maximum value nearly 3.75 for soil type I.
4. For low-rise structures the earthquakes with small magnitude are important but for medium to high-rise structures that have periods greater than 0.3, high magnitude earthquakes control the response spectra.
5. The earthquake time history has no significant effect on response spectra.
6. The spectral values are larger for earthquakes within 10 Km from the site than the earthquakes with longer epicentral distances.
7. The effect of damping on response spectra depends on soil type and the period of structure.

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